DESIGN AND ANALYSIS OF COMPOSITE ISOGRID FOR BRIDGE CONSTRUCTION

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ABSTRACT

This paper describes the use of continuous composite isogrid structures for potential applications in bridge decks. Preliminary design and analysis are presented showing the capability and reliability of this structure. Fabrication, and mechanical and thermal properties for the structure are presented. Low cost materials and fabrication techniques available are also discussed.

INTRODUCTION

Highly engineered composite structures for space and missile applications must meet a variety of properties depending upon their function. These structures also offer the potential of replacing traditional metallic structures due to their high strength to weight ratio, flexibility in design, custom tailoring of desired properties, the ability to perform reliably in different extreme environments, reduced thermal stress, and longer life.

The isogrid construction with continuous graphite fibers has proven to give exceptional stiffness and lighter weight to flat panels. They are immune to atmospheric corrosion. Recently serious concerns have been raised in the civil engineering community about the deterioration of thousands of bridges in our national highways because of severe corrosion of steel reinforcements in concrete decks. Carbon composite isogrid could be presented as a serious alternative to steel reinforcement with minimal use of concrete as filling and wear resistant material. Despite possiblly a higher material cost fiber composite isogrids can offer a competing advantage of higher speed of construction. With increasing highway traffic, motorists are becoming more intolerent of delays during the building or replacement of bridge decks. Their impatience also increases the risk of accidents. Also the current bridge construction requires long lead time both in the design and manufacture. Metal bridges are heavy, expensive, require long lead times, susceptable to corrosion, and damage easily due to thermal stress within the main structure.

A methodology for designing composite isogrids has been developed. The methology is based on optimizing the margins of safety for rib buckling, pocket buckling, and general instability. An automated procedure was used to modify the isogrid geometrical parameters (rib height, weight, skin thickness, and triangle height) in the presence of multiple contraints (maximum rib height to width ratio, until the design criteria was satisfied. A nodal area was also included in the design and geometric patterns as shown in Figure 1.

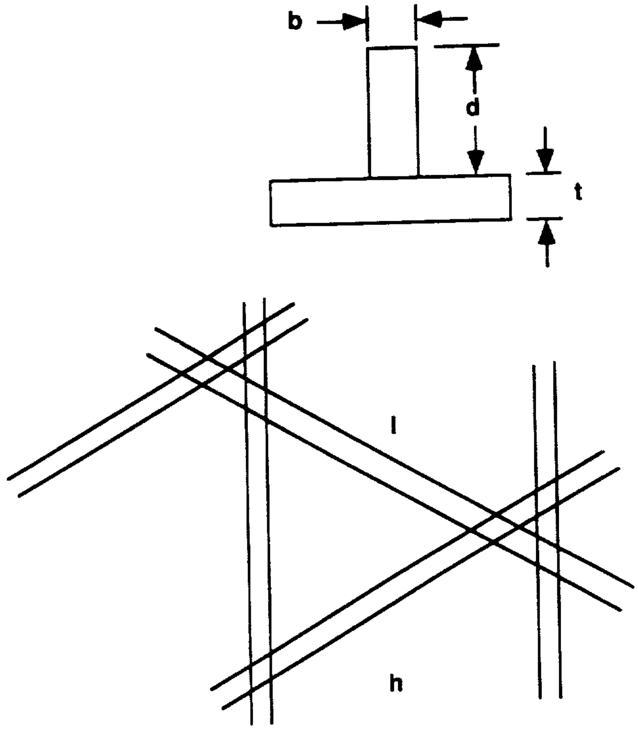


Figure 1 Isogrid schematic and dimensions

Several flat carbon/epoxy composite isogrid panels were fabricated and tested in axial compression to validate the design methodology. Multiple strain gages were used to measure the strain present in the skin and ribs at failure. Failure load levels agreed well with the pretest predictions.

TECHNICAL DISCUSSION

This effort was initiated in Jan 1990 at the US Air Force Phillips Laboratory under the direction of James L. Koury. A team consisting of technical personnel from the Air Force and Mc Donnell Douglas Space Systems Company conducted fundamental research into the processing science related to the automated fabrication of large composite isogrid structures [1]. This was followed by design development, fabrication, structural testing and evaluation.

Design and Analysis

A detailed cost and performance trade study was performed by Mc Donnell Douglas Space System Company, Huntington Beach Ca.,(MDSSC) in support of the Advanced Launch Vehicle System(ALVS) [2]. The study compared composite isogrid design to composite honeycomb, composite corrugated, composite monocoque, and traditional alumium isogrid design [3]. A comparison of weight differences is shown in Table 1. These weight differences in various lengths of isogrids are shown in Figure 2.

Table 1 - ALVS fairing design - weight comparison

Material Type	Weight (kg)
1. Composite monocoque	15875
2. Aluminum isogrid	7821
3. Composite sandwich	5020
4. Composite corrugated	4850
5. Composite Isogrid	4428

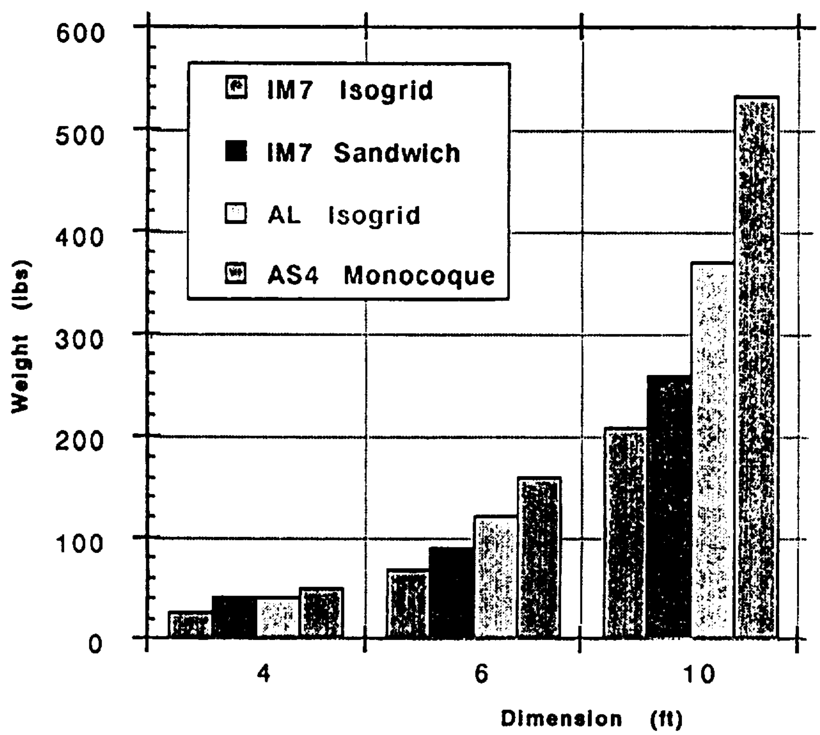


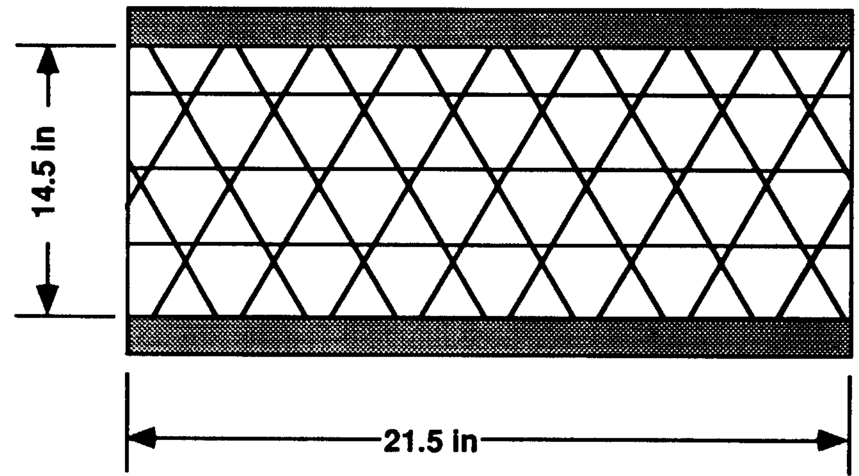
Figure 2. Weight comparisons of Isogrids ofdifferent materials

A design model was developed as part of this effort. The model has been validated by mechanical tests, plate equation prediction [4] and finite element analysis performed on composite isogrid panels [5]. Three point bend tests were also performed to validate the predicted effective modulus with the experimetal effective modulus. The results of the tests results are shown in Table 2.

TABLE 2
ISOGRID PANEL TEST RESULTS

Compression Test

TEST #	MAX LOAD (lbf)
1	8556
2	8459
3	8101
4	8102



3 PT BEND TEST

Experimental Effective Modulus	Predictive Effective Modulus
1.1 Msi	
1.21 Msi	1.28 Msi

Natural Frequency (Hz)

Experimental Frequency	Finited Element Prediction	Plate Equation Prediction
309	326	
296	323	305

WEIGHT = 1.8125 lbs
RIB THICKNESS = 0.0534"
RIB HEIGHT = 0.6208"
SKIN THICKNESS = 0.694"

FABRICATION DEVELOPMENT

The several processes involved in manufacturing composite structures are shown in Figure 3.

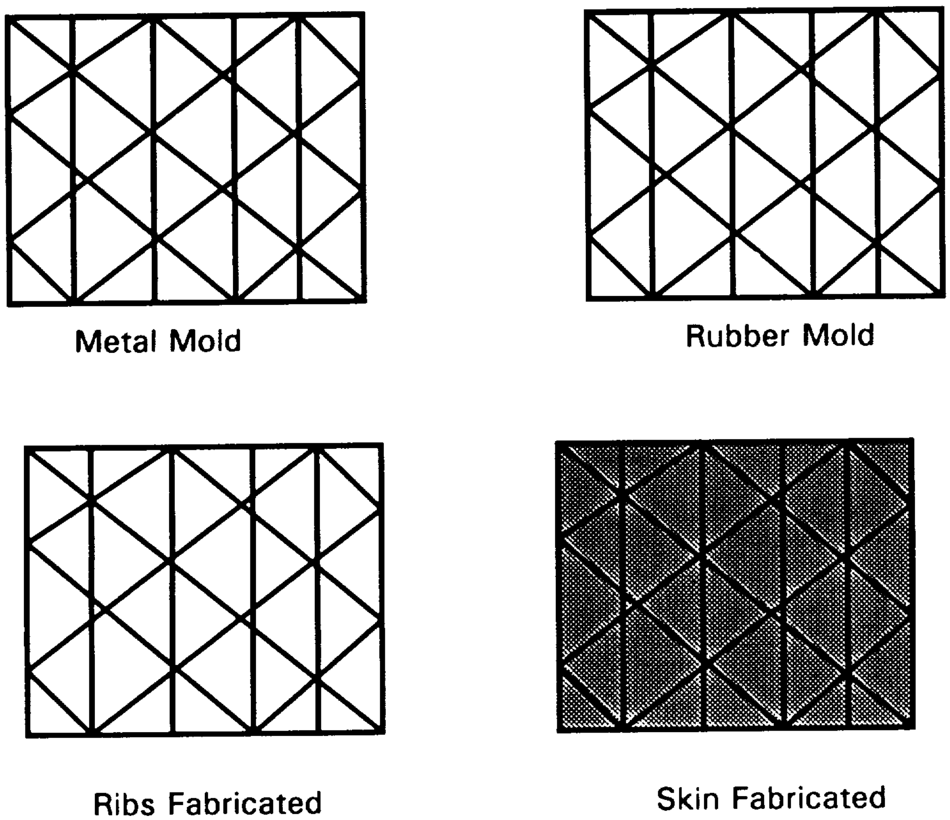


Figure 3. Fabrication of Composite Isogrid Panel

The fabrication of the composite isogrid panels starts with the development of the design for metallic isogrid mold. The pattern for the mold is generated using 2D cad design. A patterned metallic isogrid tool was first fabricated. Then silicone rubber was poured into the metal mold and formed the isogrid female rubber mold. Prepreg tow with various types of Graphite fiber and resins were fabricated into the mold followed by the skin, cured and tested. Panels with IM7/ 977-2 toughen epoxy IM7/ BYTE-1 Dicyanate resin have been fabricated, and tested. The results of the tests identified that the design for fairings, solar panels etc. are achievable. Excellent properties were validated as shown in Table 3. Mechanical tests were performed on the panels which demonstrated that the structures to have excellent strength and stiffness. The testing of the panels also demonstrated no global buckling. Damage was confined within the cell (s) thus not causing other cells to fail.

Table-3. Test data from Dicyanate ester/IM-7 panel

a. Compression Test Results

Layup	Width (in.)	Thickness (in.)	Modulus (psi x 10^6)	Compressive Strength (psi x 10^3)
0°	0.502	0.047	18.04 (0.25)*	-
0°/90°	0.500	00.061	11.14 (0.17)	-
0°/90°	0.502	0.062	-	98.1 (5.0)

b. Tensile Test Results

Layup	Test Type ASTM	Width (in.)	Thickness (in.)	Max. Load (lb_f)	Tensile Modulus (psi x 10^6)	Tensile Strength (psi x 10^3)	Ultimate Strain (x 10^{-6})	Poisson's Ratio
$[0°]_8$	D3039	0.502	0.047	8215	22.87 (0.53)	349 (15.2)	12151 (765)	0.281 (0.02)
$[90°]_{16}$	D3039	1.002	0.092	502		5.49 (0.56)	5643 (303	-
$[45/135°]_{2S}$	D3518	1.002	0.049	1184	1.82** (0.06)	23.8 (0.9)	-	0.88 (0.057)

* Figures in parenthesis show the standard the standard deviation.
** Shear modulus = 0.55 x 10^6 psi. (Std. dev. = .016 x 10^6 psi).

THERMAL STRESSES

The thermal environments that one would envision for bridges are considered minor as compaired to Air Launch or National Aerospace Plane environments that are using composites. Composites cylinders have been known to survive the severe temperature for Air launch rocket motors (-65 F to + 300 F). The fabricated structures have been subjected to thermal shock and cycled 10 times within the above temperatures with minimum degradation to the structural performance. The major concern is the resin microcracking during the curing and thermal cycles.

Thermal stresses generated during the curing of the structure, high percent of voids and the high percent of water uptake must be understood and taken into account during the design of the structure. There is an extensive amount information in the literature on the types of resins that have been evaluated and can be used for the above applications [3][6][7]. The insertion of toughened epoxy and toughened dicyanate resins have expanded the resin's thermal capabilities. The National Aerospace Program (NASP) has developed and demonstrated the use of these types of resins for low (Liquid Hydrogen) temperatures for space applications. NASP Technology programs have successfully fabricated and tested composite cylinders, without metal liners, to contain liquid hydrogen. Cylinders were thermally cycled ten times to -423 F and Pressure cyles to limit pressure six times at -423 F with no hydrogen leakage and no structural distress. This technology has also identified that one must not only select the resin but must also design the composite structure in such a way to minimize and control the microcracking during the life of the structure.

As a result of this past effort the Phillips Laboratory is planning a program to design and fabricate two four foot cylinders and perform similar Liquid Hydrogen Leak Tests. This effort is in support of Single Stage To Orbit (SSTO) program. The resin that will be used on the above program has been tested by NASA and is the leading candidate for the SSTO program. B based allowables data have been performed for the resin material shown in Table 3.

TARGETED APPLICATIONS

The composite isogrid technology presented here has many other applications. However, the major concern is the materials and the fabrication costs. The materials cost for glass /epoxy and graphite/epoxy are high. In aerospace industry the major cost driver is the contractor/goverment control requirements. The number of test required for material validation i.e. A and B allowables performed by the manufacturer to validate the manufactures data drives the costs. A program is needed to assess the cost drivers, and determine if the requirements used by the government/contractors can be altered for use of the composite isogrid technology for civil engineering application, and thus reducing the costs. Also, the production rates for space and missiles is much lower than what would be for infrastructure applications, where much larger volume of materials will be needed. The increased demand and the high production rates should bring the overall cost down, thus making the composite very competitive with conventional bridge decking materials. The life cycle costs should also be evaluated for composites. The long life prediction for the composites should reduce the life cycle costs thus reducing the over all cost significantly.

CONCLUSIONS / RECOMMENDATIONS

The composite isogrid technology is ready for insertion into the commerical arena. The Technology developed by the Phillips Laboratory has validated the analytical models for panels. Low cost filament winding process has been demonstrated. Automation of the isogrid is just around the corner but needs government support. The design and resin technology has been demonstrated and is ready for commercialization. The only thing that one must be concerned with is the cost. We recommend that a program be generated to determine if the material and processing cost is ready for this area. In conclusions, I feel that this technology is ready for demonstration and implementation.

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